Automating The Operations Of NASA's Deep Space Network 26-Meter Antennas [1]

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Abstract- A development effort has been embarked on with the goal of improving the automation of some key components of NASA's Deep Space Network. This automation is intended to allow the DSN to support more missions with smaller budgets and fewer people. The development of these automation capabilities required not only a new set of hardware and software components, but also a significant change to the operational concepts that have been used to drive the design of the DSN for the last 20 years. This change to the DSN's operational scenarios should have an impact on future developments for all components of the DSN.

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1. Introduction

While every part of NASA is striving to find ways to meet its mission faster, better, and cheaper these days, the pressures to do more with less on what are considered "routine operations" are even greater. NASA's Deep Space Network (DSN) is working hard to find ways of supporting an ever increasing mission set within a steady or declining budget. One way that the DSN is looking to meet this challenge is to enable a decreasing operations workforce to support more missions through the use of increased automation. An effort has been underway for the last two years to introduce some new automation techniques into one portion of the DSN, and change the way some routine operations are supported. This paper will examine this automation effort, first by trying to understand the history of the DSN that has led it to the present day. This paper will then examine changes to the traditional DSN operational scenario implied by this new automation. The paper will discuss the details of the design for the new hardware and software implemented at the DSN's 26-meter antennas. Finally, this paper will attempt to forecast what the lessons of this effort may mean for the rest of the DSN and other potential ground tracking systems.

2. History of the DSN's 26-meter Antennas

The DSN is NASA's key telecommunications asset for the tracking of spacecraft outside of low earth orbit. The DSN is also used to support the launch and early orbit phase of many NASA, commercial, and international spacecraft. The key components of the DSN are three deep space communications complexes (located at Goldstone in the California desert, outside of Madrid, Spain, and outside of Canberra, Australia), and the network operations control center in Pasadena, California. The Jet Propulsion

Laboratory (JPL) of the California Institute of Technology has the responsibility for the development, operations, and management of the DSN for NASA.

Each of the deep space communications complexes has a collection of large steerable radio antennas, as well as a local signal-processing center that serves as the operations center for that complex. The radio antennas of the DSN have main reflectors with diameters ranging in size from 11-meters up to 70-meters. The larger diameter (34-meter and 70-meter) dishes are typically used to support robotic missions to the planets and other cosmic objects that make up our solar system. The smaller diameter (11-meter and 26-meter) dishes are typically used to support robotic missions in earth orbit that cannot be supported by other NASA tracking assets, such as the Ground Network (GN) or the Tracking Data Relay Satellite System (TDRSS). The focus of this paper is the three 26-meter antennas of the DSN, one located at each deep space communications complex.

The 26-meter antennas are some of the oldest antennas used by the DSN. The structures were originally built under the direction of NASA's Goddard Space Flight Center to support the Apollo manned space program. The main reflectors of the antennas are on an X-Y mount and controlled by a hydraulic drive system (See Figure 1). The microwave electronic systems on the antennas support uplink and downlink operations in the S-band frequency range. In addition, two 1-meter wide-beam acquisition antennas are mounted on the edge of the main reflector. These acquisition antennas are used during launch support activities for the initial acquisition of S-band and X-band signals. Once the acquisition antennas have locked onto the spacecraft signal, the information is used to help drive the main 26-meter antenna, or other DSN antennas, to the spacecraft signal.

Following the conclusion of the Apollo Program, the 26-meter antennas continued to support manned space missions, and they began to also support robotic spacecraft in earth orbit. With the development of the TDRSS, the 26-meter antennas were no longer required for prime manned mission support. In the early 1980's, NASA transferred three of the Apollo antennas to JPL and the DSN. The prime mission for these 26-meter antennas became the support of robotic spacecraft.

Today, most of the missions supported by the DSN's 26-meter antennas are in highly elliptical orbits, such as several of the International Solar Terrestrial Physics (ISTP) projects like Polar, GEOTAIL, and SOHO. Another key use of the DSN 26-meter antennas is the support of many NASA, international, and commercial missions that are still in their launch and early orbit phase. The DSN 26-meter subnet also provides backup support for many missions whose prime support comes from TDRSS or GN, such as the Hubble Space Telescope.

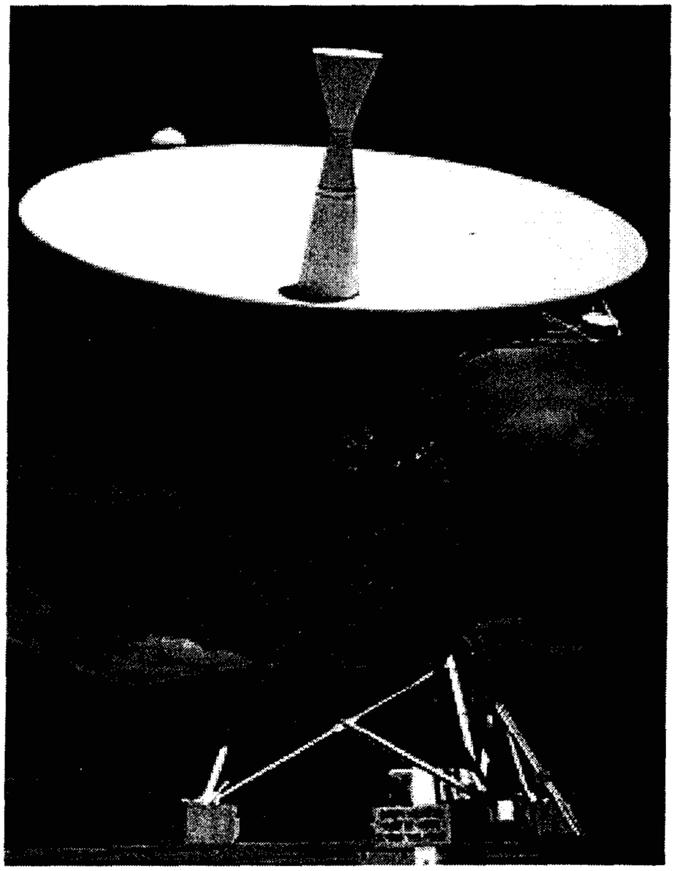

Figure 1 DSN 26-meter Antenna at Canberra, Australia (courtesy JPL/Caltech)

3. Evolution of the Operational Scenario

When the 26-meter antennas were first integrated into the DSN, many challenges arose. The operational scenario for the 26-meter antennas, the way in which operations were typically conducted, was entirely different than that of the other DSN antennas. At that time, a large staff of dedicated operators and equipment, physically located at the antenna site and dedicated solely to that antenna, controlled the operations of the 26-meter antennas. The other antennas of the DSN were operated from a central signal processing center (SPC), utilizing a combination of dedicated equipment and a pool of shared data processing equipment.

An effort was made to integrate the operations of the 26-meter antennas into the standard operational paradigm used for the rest of the DSN antennas. This effort, known as the network consolidation project, began in the early 1980's and encompassed many phases. The early phases focussed on the physical relocation and consolidation of existing hardware components, rather than the modification or development of new components. The idea behind this effort was to significantly reduce operations staffing by having the operators from the signal processing centers at each complex run the 26-meter subnet equipment. This consolidation was more easily accomplished at Canberra and Madrid due to the geographically compact nature of these complexes. Unfortunately, the Goldstone complex is spread over a very large area. The Goldstone 26-meter antenna is over 10 miles away from the SPC. This distance, combined with the need to have much of the radio frequency equipment still physically located at the antenna site, severely limited the amount of consolidation that could be accomplished.

It was soon realized that if more remote control were to be accomplished, modifications would need to be made to the equipment supporting the 26-meter antennas. In the late 1980's and early 1990's, the DSN undertook a development effort known as the Signal Processing Center Data Systems Modification Task [ref. 1]. The primary goal of this task was to update four of the primary data processing systems used by the DSN: the telemetry, command, tracking, and monitor and control systems. A secondary goal of this task was to modify some of the 26-meter subsystems so that operations on the 26-meter subnet could utilize the new data processing subsystem being installed for the other DSN antennas. The idea was that the same equipment and operators used to run the 34-meter and 70-meter antennas would also be used for the 26-meter antennas. Upon completion of this task, the staffing at each complex dedicated to the operation of 26-meter unique equipment was reduced to just one or two operators per shift. These operators were still required to monitor some remaining legacy equipment that did not have remote control capability.

The Signal Processing Center Data Systems Modification Task was considered to be a success in many ways. First, it had accomplished a higher level of integration between the various subnets of the DSN. Second, it allowed for reductions in the staffing required to conduct routine operations. Third, it gave the DSN a new base of technology upon which future improvements could be built. During the early to mid-1990's the focus of DSN development turned towards increased automation of routine operations. The larger number of missions that the DSN was being asked to support, coming at the same time the operations budgets for the DSN were being reduced, drove the desire for improved automation. The DSN needed new technology to allow it to do more with less.

Unfortunately, the early efforts to automate routine DSN operations were not as successful as desired. A number of factors caused problems which resulted in automation efforts either being considerably more difficult than planned, or producing less than the expected results. While some of these problems could be traced to deficient technology to accomplish the desired level of automation, it became clearer that many of these problems were actually artifacts of the DSN's legacy operational scenarios. In particular, the desire to have one set of equipment and one set of operating procedures that tried to handle all missions that the DSN supports, posed many problems for the automation effort.

Since the early 1980's the DSN system designers had made a conscious effort to try and centralize as much of the equipment used to support missions as possible in the signal processing centers at each complex. This centralization included the idea of using a common pool of equipment for data processing that could be switched to any antenna as needed. The data processing functions covered by this common pool of equipment included the telemetry processing, command processing, and the monitor and control functions that enabled the components to work together. Two of the key goals of this centralization effort were to ease the burden on operators by having a common interface to all equipment and antenna types, and to allow rapid switching of equipment from one antenna to another in the event of equipment failure. To a large extent, these goals were in fact met by the designs developed throughout the 1980's and early 1990's. It was the unintended consequences of this common equipment pool design that hurt the further attempts at automation.

The first of these unintended consequences was that in order to make the systems work for all missions that possibly needed to be supported, the systems became extremely complex. For example, the telemetry systems developed for the DSN were being designed to handle everything from high data rate (>1 megabit/second), and high signal strength data dumps from the Space Shuttle, to an outer planet robotic probe with its low data rates (<100 bits/second) and low signal strengths. The telecommunications needs of the users of the DSN varied widely depending upon the type of mission. While the missions may all use a common set of radio frequency bands, there is still a lot of variation in other aspects of the telecommunications link design. The large number of combinations of such parameters as multiple data rates, multiple modulation techniques, multiple coding techniques, differing doppler profiles, and different spacecraft equipment configurations made it very cumbersome for one system to handle all possibilities. Despite the best efforts of the engineers building these systems, there often seemed to be a trade-off between complexity and reliability. The end result was often a system with less then the desired reliability for all cases. This lower reliability of the key systems made the automation efforts even more difficult. After years of trying, it has become obvious that getting systems to run without operator intervention really depends on those systems behaving in a predictable and consistent manner.

Another of the unintended consequences of the DSN's consolidated centralized design was the issue of too much flexibility being built into the system. It at first seems counter-intuitive that there could be such a thing as too much flexibility, but when it comes to automation, that does appear to be the case. The designers of the DSN subsystems tried to anticipate the needs of the missions that would be the eventual users of those subsystems. They wanted to give the operators of the DSN enough choices to handle any circumstance that may arise. Unfortunately, each additional choice given to an operator running a subsystem makes the job of automating that subsystem that much more difficult. Developing software to handle the large number of choices that a human routinely faces is no trivial matter.

The difficulty in dealing with a large number of choices became especially obvious when trying to determine recovery mechanisms when equipment failed. The DSN's centralized signal processing center design relied on a common pool of equipment that could be quickly switched to provide support from any antenna. Enough copies of each data processing subsystem were included in the common pool to handle a number of simultaneous activities at any antenna complex, and to provide redundancy in case of equipment failure. Automating the assignment and switching of equipment to any one tracking activity ended up being much more difficult than originally anticipated, often requiring human intervention. For a variety of reasons, over time, not all equipment in a common pool remained identical in capabilities. Subtle nuances in scheduling developed because of these differences, and it was difficult for any automation system to track the large number of changes. Likewise, the differing priorities for different mission support activities were difficult to translate into an automated equipment selection process. For a human, it is easy to understand that a mission doing a critical planetary fly-by during a track should have priority for any equipment over a mission doing a standard tracking activity during a five-year cruise phase. Getting an automated system to understand the difference was much more difficult.

Over time, it has become obvious that in order for the DSN to make better gains in the area of automation, a new operational scenario needed to be developed. The new scenario that is now being used in the DSN has come to be known as station centric operations.

4. Station Centric Operations

The key concept of station centric operations is that any tracking station will have direct control of all of the equipment it requires to support any mission. The old common pool concept is abandoned. A dedicated station controller handles coordination of the activities at a given antenna, while coordination of activities between antennas is still handled by a centralized controller. JPL conducted early technology demonstrations of some of the key concepts that have come to be known as station centric operations with the Low Earth Orbiter Terminal (LEO-T) [ref. 2] and Deep Space Terminal (DS-T) [ref. 3] developments.

The idea behind giving a station controller full control of all equipment for a given antenna is that it greatly simplifies the design of any automation system for that antenna. With a known, and limited, set of equipment available to the station controller, there are many fewer options and choices that need to be considered when attempting to automate routine operations. The automation system does not need to worry about as many possible failure scenarios, thus having fewer recovery scenarios that need to be considered. With fewer permutations possible, more effort can be devoted to dealing with those that do remain.

Another advantage of station centric operations is that there is also much less effort involved in the monitoring of the health of the systems. With the common equipment pool concept, a great deal of effort was spent on designing and implementing a very complex exchange of monitoring data between subsystems. This monitor data flow was made more difficult by trying to allow any subsystem in the common equipment pool to communicate with any other subsystem that might be used to support the same tracking activity. Again, it became a case of increasing combinations and permutations. In the station centric scenario, it is known a priori what equipment will need to communicate with what other equipment. The entire interchange of monitor data can be designed to be much simpler.

Of course, there are some potential drawbacks associated with the switch from the staffed common equipment pool scenario to the automated station centric scenario. Two such drawbacks are potential decrease in the ability to recognize a failure, and the loss of some redundancy with its associated potential for lost mission data. The common equipment pool design and constant operator attention made it fairly routine to recover from most equipment failures during an activity. A human operator can do a good job of recognizing a failure, identifying the cause of the failure, determining if a spare for the failed assembly was available in the common equipment pool, and then, assuming the availability of that spare, swapping to the spare. It is generally recognized that an automated system will not be able to match the sophistication of a fully staffed system. There will be certain failure modes that the automated system may not be able to recover from, and as a result, there is some likelihood that there will be some small decrease in the data delivery performance metrics of the 26-meter antennas. Given the nature of a typical mission using the 26-meter antennas, JPL has taken the position that the increased risk of data loss is acceptable when compared to the potential for substantial cost savings.

5. Development of New Capabilities

The basic concept of the automation effort for the 26-meter antennas of the DSN was to provide an operations capability as autonomous and automatic as possible within the funds available. This was accomplished through significant use of existing components and Commercial-Off-The-Shelf (COTS) capabilities and a reduction in implementation costs.

In an effort to make this automation a reality, JPL contracted AlliedSignal Technical Services (ATSC) to evaluate the successes and failures of previous automation efforts and to develop a design to automate the 26-meter antenna. ATSC was tasked with developing a new operational scenario that lent itself to the autonomous and automation operations concept of the future. ATSC was also tasked to investigate currently available COTS software and equipment that could possibly be used to replace the functionality of the data processing equipment from the SPC common equipment pool. The primary emphasis was placed on substituting the current equipment within the Monitor and Control and the Telemetry and Command Subsystems with new, reliable, technically current software and equipment.

ATSC analyzed the operational capabilities and the usage of the existing equipment at the 26-meter antennas. Keeping in mind that the 26-meter antenna was to be separated from the rest of the DSN, and that it was to require few or even no operators, ATSC developed a new operations baseline. This baseline was reliable and self contained to the maximum extent possible. The new operations baseline only requires operators in the event of an emergency, or for support of launch and early orbit phases of missions. Because of the reduced exposure of the operator to the new automated system, the operation of the system was designed to be simple and intuitive. The baseline required significant use of the "point and click" operations methodology.

In an effort to produce a reliable, automated system, major emphasis was placed on reducing the system complexity of the 26-meter antennas. Given the previous efforts that the DSN had placed on consolidating the various subnets of the DSN and to automate the routine DSN operations, it became apparent that for the successful automation of the 26-meter antenna, a dedicated string configuration was required. The legacy operations scenario, during which various pieces of equipment could be sampled for best performance and then selected for the mission support, could not longer be followed if the automation was to become a reality. The ultimate implementation included dedicated strings with dedicated equipment, with no switching capability between strings.

Industry was surveyed for software and hardware that best adapted itself to the requirements of the 26-meter antenna. ATSC, with their past experiences developing automated systems for the Goddard Space Flight Center (GSFC) and other organizations, and knowledge of currently available COTS software and hardware, identified the items most applicable for the automation of the 26-meter antenna. For the Monitor and Control Subsystem, the WonderWare InTouch and the OmniServer COTS software packages were selected along with a PC using the Windows-NT operating system. For the Telemetry and Command Subsystem, the Telemetry and Command Processor (TCP) manufactured by Avtec Systems Inc. was selected. The TCP also resides on a PC using the Windows-NT operating system.

Subsystem Design

The new design for the 26-meter antennas consists of three major subsystems: the Monitor and Control, the Telemetry and Command, and the Radiometric Subsystems (refer to Figure 2.) The functions of the automation capabilities are split between these three subsystems. The Monitor and Control Subsystem (MCS) provides the central monitor and control functions, including anomaly resolution, of all 26-meter elements, and interfaces to the external entities for transport of the 26-meter monitor, schedule and acquisition data. The Telemetry and Command Subsystem (TCS) provides all of the telemetry and command functions and interfaces with the external interfaces for the transport of the telemetry and command data in near real-time. The Radiometric Subsystem (RMS) incorporates all RF-related functions and the antenna control hardware.

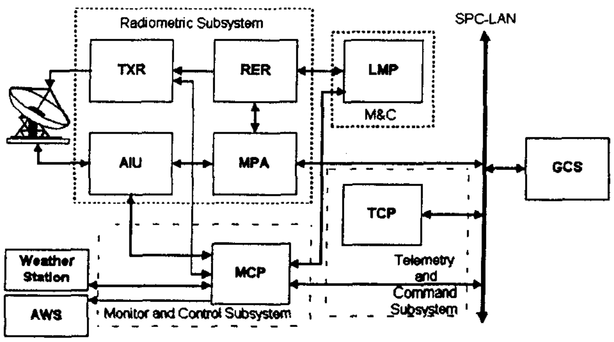

Figure 2: 26-meter Subsystems

Analysis of the 26-meter antenna revealed that reuse of many of the existing components, with slight modifications or augmentation, was required for the desired autonomous operations. Major modifications were required for the MCS and the TCS. These subsystems required modifications, augmentation, and/or replacement of equipment to support the automated operations of the 26-meter antenna.

Figure 3 illustrates the 26-meter subnet context diagram. External inputs provide the necessary information and command data relevant for the autonomous operation of the 26-meter subnet to support the mission set. Data is output from the 26-meter subnet to the projects and other external elements.

As illustrated in the diagram, the navigation predicts, contact schedules, and commands are received through external communications elements located at the SPC. Station control is autonomous or received from a manual input source at the station. The telemetry data, tracking data, and the 26-meter subnet status information are transmitted from the 26-meter subnet to the external elements at the SPC.

The design of the system also needed to ensure that failure at the MCS did not impact the spacecraft pass, provided configuration parameters had already been processed by the other subassemblies. The design accounted for the use of processors within the subsystems to support the real-time functions, including antenna pointing, ranging, telemetry processing and command, to continue undisturbed.

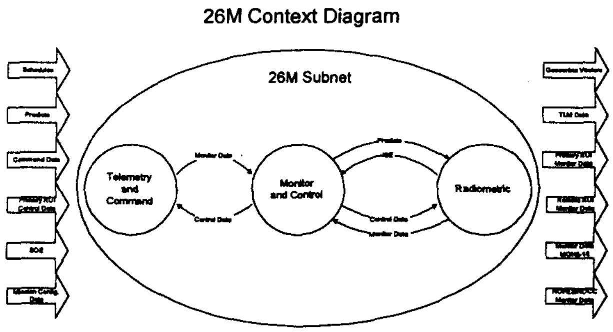

Figure 3: 26-meter Context Diagram

ATSC chose to use two COTS software packages to reduce the development cycle for the autonomous operation of the MCP for the 26-meter subnet. The InTouch man-machine interface (MMI) software, developed by WonderWare Corp., was used to provide the graphical user interface (GUI) and scripting for the automation. OmniServer, a configurable device driver, by Descartes Systems Sciences was used to provide the serial interface between legacy equipment included in the automation effort and the TCP/IP communications protocol with the new computer based subsystems. Each of these packages was used by ATSC on other remote control/automation projects for NASA-- most notably were the MILA/Bermuda Re-Engineering Project, which was a major upgrade of Shuttle launch support facilities, and the University of California, Berkeley, ground station for the High Energy Solar Spectroscopic Imager mission. These previous development efforts provided a cadre of experienced personnel and allowed the reuse of portions of some previously developed applications.

The InTouch MMI is based on a database system that houses status and control information. Device drivers move status parameters from the end equipment into the database and conversely move control actions from the database to the end equipment. The database can be manipulated by a GUI to present information to an operator, or by scripting and other programs, if automation is desired. Any software package that can read from, and write to the database, can be used to add increased functionality. This allows future improvement, such as adding an artificial intelligence shell without redeveloping the application.

ATSC also chose the Avtec Systems; Inc. TCP to support the autonomous operations and the mission set drivers required for the 26-m antenna. The TCP is a COTS item meeting the time tag resolution requirements, the various telemetry data formats, telemetry block formats, the broad data rate requirements, and the mission unique parameters currently supported by the 26-meter antenna. The TCP has been used by ATSC for other automation projects, such as the LANDSAT 7 Ground Station for NASA.

Operational Overview

In general, operations for the 26-meter subnet are driven by a combination of data base parameters and tasks executing in a GUI based software system that is running in a real-time operating environment. The data base parameters define the run-time configuration, while the tasks are used to determine the sequence of operations.

MCS- The Monitor and Control Processor (MCP), part of the MCS, provides autonomous operation of the 26M subsystem. The MCP is the focal point of all monitor and control functions for the 26-meter antenna. The MCP is the central point for receiving schedules, acquisition data, and the sequence of events. Listed below are key characteristics of the MCS:

- maintains configuration of the 26-meter equipment;
- utilizes a graphical interface providing a quick look status of the 26M activities;
- distributes acquisition data to required equipment;
- provides logging capability;
- provides Track activities;
- provides Alarm logging;
- processes schedules and the schedule of events to perform automation sequences at predefined times;
- reconfigures to the last known configuration in case of MCP failure;
- provides an interface for remote operations;
- provides the audio capability to broadcast antenna activities.

The 26-meter automation system receives schedules and acquisition data from a system located at JPL. It identifies the next scheduled event and proceeds to download the acquisition data to the antenna pointing subsystem, and to call up equipment setup parameters from a mission configuration table (MCT). These parameters are downloaded into each piece of equipment that is required to support the event. After the equipment parameters are downloaded, the configuration is verified by performing pre-event tests. When pre-event testing is completed, the antenna is moved to its initial position. When the event starts, the spacecraft is acquired and telemetry and command data flows are initiated. During the data flows, the equipment status is monitored, logged, and sent to the end user. When the spacecraft tracking activity is completed, the data flows are terminated and a post-pass summary report is generated. The antenna is returned to a pre-determined position provided that another event is not ready to start.

InTouch's ability to change equipment setting based on user developed scripts is the key to making the events described above occur in an automated method. This function enabled the ATSC engineers to develop and test individual components of the system, and then develop the scripts to make the entire system function as an integrated entity.

The sequence of events (SOE) process was developed to accept JPL keywords and then to translate them into detailed equipment commands. The SOEs detail the events that are to occur during the pass. Nominal SOEs are resident in the MCP. These SOEs list the events that are to take place for a particular mission. The events include such items as the time to enable the transmitter drive power, the start and stop time of the telemetry data flow, playback functions, the beginning of track times, end of track activities, performance readiness tests, etc. InTouch reads the received SOEs on a mission by mission basis, and processes and performs the events listed in the SOE in real-time.

Figure 4 illustrates the top-level screen of the MCP. Since this is typically an operator-less system, only relevant information is provided for an "at a glance" look for the health and safety of the 26m subsystem. Any detected anomalies are visually and audibly available to alert the operators within the SPC Control Center. Anomalies will cause the subsystem to revert to the backup string or to halt the antenna, depending on the severity of the anomaly detected. The capability for manual intervention is also provided.

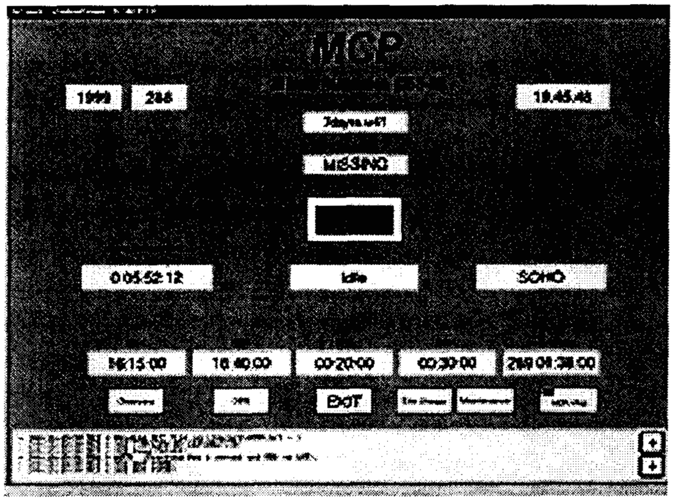

Figure 4: MCP Top Level Screen

TCP- The Telemetry and Command Processor (TCP), supplied by Avtec System, Inc., is part of the 26M TSC and provides the capability to support the telemetry and command functions required by the current mission set.

The new 26-meter configuration utilizes two TCPs. These replace the existing SPC-based telemetry and command common equipment pool elements. Each telemetry and command string has dedicated equipment to support the mission. The existing SPC telemetry and command elements will remain undisturbed for continued use by the other DSN antennas.

Figure 5 provides the TCP Subsystem interface diagram. The TCP Subsystem is responsible for processing telemetry and command data during the pass. Data is transported to the projects in real-time, as well as being recorded for post-pass playback. The TCP Subsystem communicates with the MCP for monitor and control purposes and the transfer of data quality and data accountability statistics. The data quality and accountability statistics include, but is not limited to, the bit synchronizer status, the individual virtual channel processor status, playback status, recorder status, the serial input/output status, socket status, the bit error rate status, and the TCP/IP connection status to the external entities.

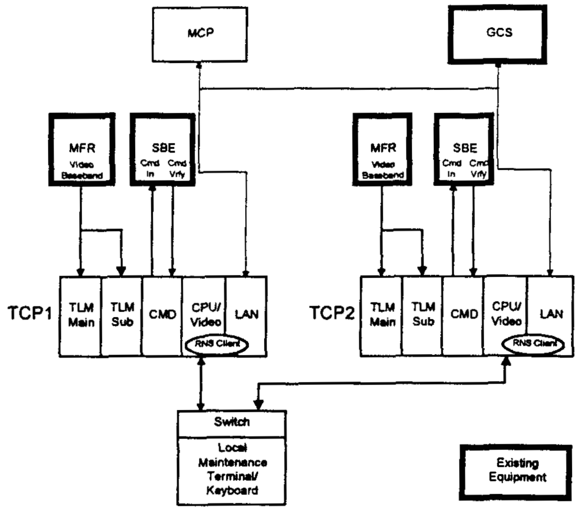

Figure 5:TCP Subsystem Interface Diagram

The second TCP is provided as a "hot" backup in the event of any TCP anomalies. It can also be utilized for missions that require two simultaneous telemetry streams. Both TCPs have a socket connection established for transport of data, but only the primary TCP actually transmits the telemetry data to the projects via the TCP/IP connection. Of course, the exception to this is for the dual telemetry stream missions. In this case, both TCPs transmit telemetry data to the project.

The TCP supports the various missions by loading the appropriate pre-designed desktop. These desktops are a key element for the proper operation of the TCP. Based on the mission to be supported, the MCP identifies the desktop to be loaded into the TCP. These desktops are built using the parameters necessary to configure the TCP for a given pass. Each Mission perturbation has its own associated desktop. Some of the included parameters are the mission specific subcarrier and carrier frequencies, bit rate, input and output code (BiPhase-L/S/M, NRZ-L/S/M), frame length, etc. New desktops are easily created to allow for the expansion of the automation system to support new missions.

These desktops are loaded prior to the required mission support. They are tested against a localized Equipment Performance Test (EPT). During the EPTs, all required external interfaces for the pass are established. The MCP initiates the EPTs. The EPTs are run using both TCPs. One TCP simulates the spacecraft; the other receives the data, and controls the EPTs.

Summary

The new autonomous 26-meter antenna system provides a robust system operating under the control of schedules, SOEs, and MCTs. Operator intervention is only required during launch and early orbit support, emergency commanding, and anomaly conditions. Most failure conditions are rectified by the use of the redundant telemetry and command strings.

The MCP is the central processing unit which receives all of the monitor and control parameters associated with each support. Initially, the schedules are received and processed to determine the time of the next mission support. The MCP prepares for the support by first configuring the subsystem elements at the specified times, and then by loading necessary parameters listed in the MCT.

The SOEs are processed to determine the scheduled events that are to take place to support this pass. Based on the SOE and system time, specific events are triggered. These events cover all activities occurring during the entire support timeline.

The MCP monitors the health and status of the 26-meter antenna during the scheduled pass and logs all activities into the mission file. A post-pass summary report is generated from the log. Both the post-pass summary report and the log file are forwarded to the projects.

Anomalous conditions are handled per the error handling routines resident in the MCP. The antenna will be returned to its stow position or halted only if the detected anomaly is severe or cannot be recovered.

If an anomaly is detected during the initialization process and it cannot be corrected, the MCP will determine whether or not the pass can still be supported. If the anomaly is detected in the telemetry or command string, the MCP will force the telemetry and command string to switch to the redundant string.

During a telemetry data dump from the spacecraft, the TCP formats the block per the JPL format and transports the data to a network server where the projects can access the data. Similarly, during a command uplink to the spacecraft, the TCP receives the command data directly from the project. The TCP uplinks the command data on the specified carriers and transmits the data to the spacecraft. The telemetry and command data transport is handled independently of the MCP control. The MCP retrieves data accountability information on the operation of the TCP.

A Remote User Interface (RUI) for "spot checking" the operations of the 26-meter antenna is provided at the SPC and at the network operations control center in Pasadena. The RUI displays are identical to the MCP displays and provide adequate information about the health and status of the antenna. If necessary manual control capabilities are available from the RUI to modify the configuration and support parameters. All of the automated functions are manually controllable from the RUI or the MCP, using the "point and click" methodology.

6. Future Considerations

The automation system designed for the 26-meter antennas of the DSN is viewed as a first step towards ever increasing automation of routine operations. The system deployed to the antennas is intended to be the basis for future improvements. The designs of the operational scenarios, the hardware, and the software were planned to be flexible enough to allow easy modification and addition of new capabilities. The use of commercial products whenever possible should make it easier to keep the system more up to date with current technologies than it was in the past.

The new autonomous 26-meter design allows for future growth to possibly provide monitor and control capabilities for all three 26-meter antennas, one at each of the DSN complexes, from one central location. Future enhancements to the operations of the antenna, or replacement of the equipment in is current configuration, can be more easily accomplished through the InTouch software package. This is because it is a database driven system requiring little to no software experience.

One capability expansion effort already underway for the 26-meter automation system is the addition of support for the Space Link Extension (SLE) standards of the Consultative Committee for Space Data Systems (CCSDS).

It is hoped that lessons learned from the effort to automate the 26-meter antennas of the DSN can be translated into successful automation efforts for the other antennas of the DSN. Station centric operations scenarios for deep space mission support are already being developed. The Network Simplification Project, a major new development program for the 34-meter and 70-meter antennas, has now been started. Many of the same concepts that were first used in the 26-meter automation effort will be used on this project.

7. Conclusions

It has now become possible to achieve a level of automation in the DSN that has previously been unattainable. This new level of automation is made possible by a couple of key changes: a new operational scenario, and the introduction of new commercial technologies. The introduction of this new automation system into the DSN 26-meter antennas is just a first step in future efforts to continue to enable the DSN to support an increasing number of users within a decreasing budget.

Biography

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